Investigation into the soil characteristics on the North and South facing slopes of the Hermitage of Braid, Edinburgh

Word Count (excl. title, diagrams, appendix and references): 3028

Introduction

Soils form a vital role in the Earth's ecosystem; it influences the spatial distribution of organisms, and also life's food system. Soil science is an important area of study, especially in the 21st Century, as human activities pose a threat and change the properties of soils. Pedology, thus, is of inherent value to humans.

Soils are formed from the weathering of parent rock or glacial till left from glacial activity during the Quaternary period to give regolith. The breakdown can be termed as a *state of equilibrium* with its environment, meaning an 'object is adjusted to the external forces acting upon it'.[1] *(Courtney and Trudgill, 1976).* The complex interactions between the regolith, climate, soil biota, and topography of the land majorly affect pedogenesis of British soils.

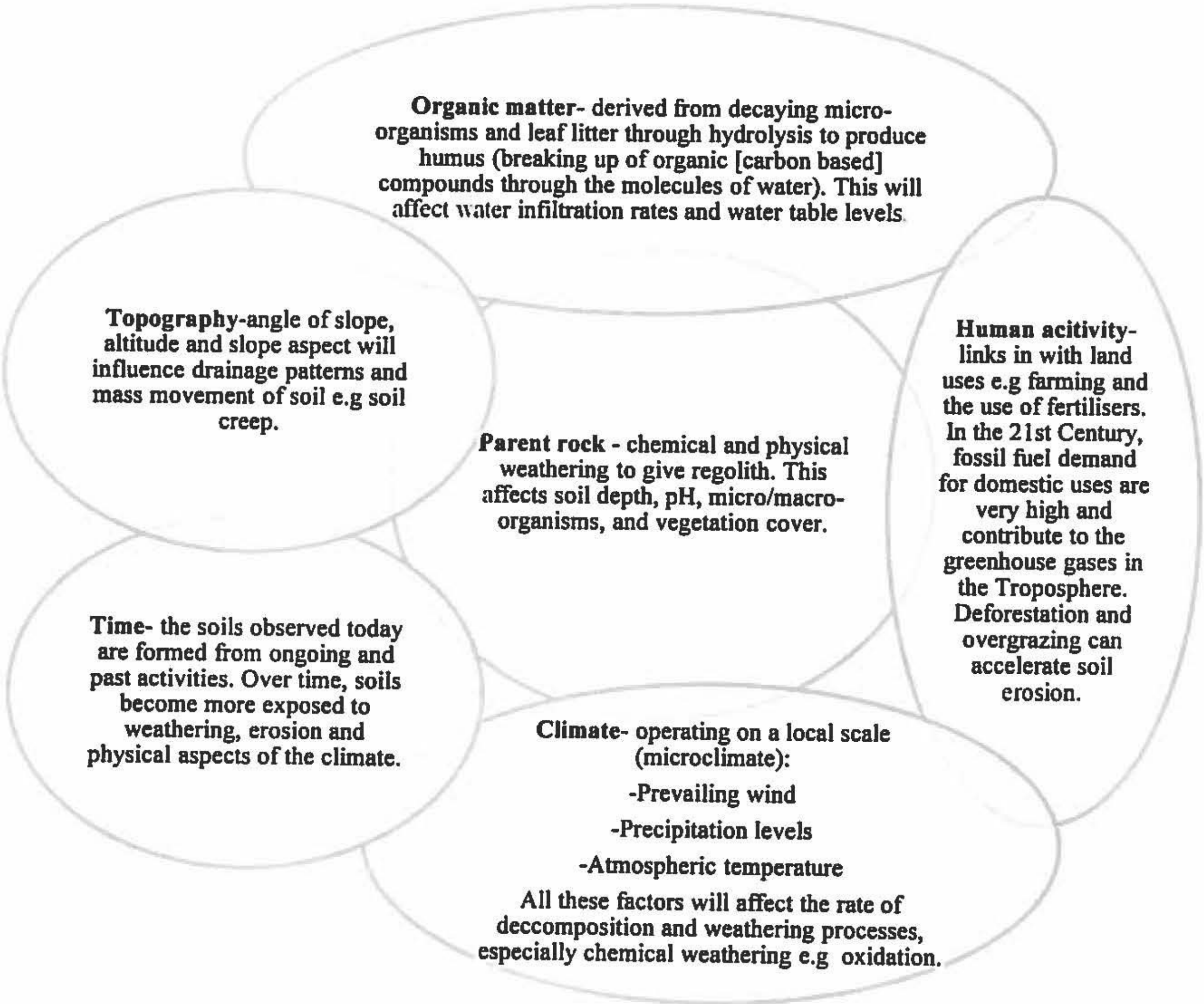


Figure 1
Venn diagram showing the interactions between soil formation factors
(Source: Author's own diagram)

Soil Catena

The model highlights the influence topography has on the hydrological sequence of soil profiles which develop downslope, assuming parent rock is uniform along the transect. After glaciation, much of the upper slope was waterlogged, and this promoted the spread of hydrophytes. The impermeable subsoil provides evidence of a reasonable lateral sub-surface flow and a water table at considerable depth, giving a moderately well-drained soil; this leads to the leaching of organic matter. Soils are poorly drained at the footslope and toeslope, as it lies in the zones of intermittent and permanent saturation, meaning there is no escape of water for most of the year.

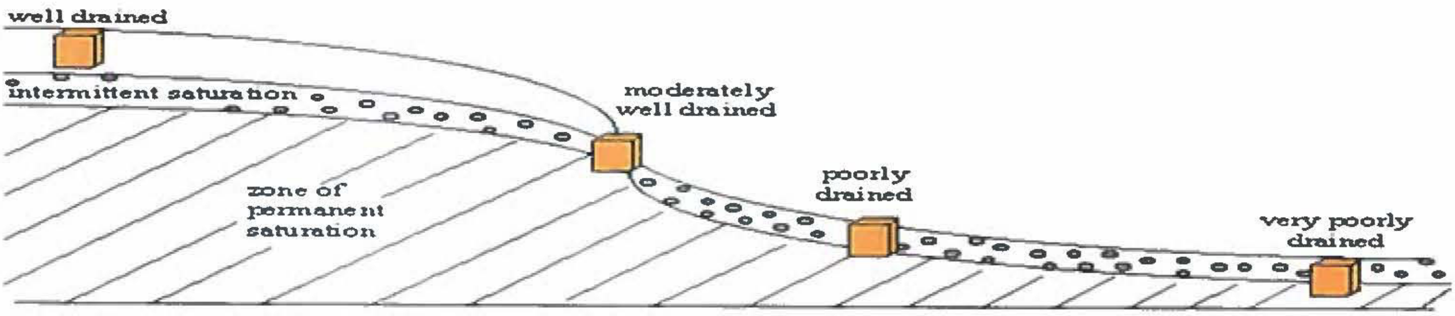


Figure 2
Soil catena showing the relationship between drainage and hillslope
(Source: soils.ifas.ufl.edu)

What is of interest in this study is how drainage might differ on contrasting slope profiles in the Hermitage Valley of South Edinburgh.

Figure 3
Looking on the woodlands of the Hermitage of Braid from the South facing Wildflower Meadow
(Source: Author's own photograph)

Early signs of the development of the Braid Hills started when the Pentland Hills erupted in the Devonian period (410 million years ago). As part of the Pentland Hill eruptions, the lavas also erupted in the Braid Hills. In the late Devonian, the lavas were deeply weathered, and formed rock with altered mineral compositions from the original (trachyte and andesite). Trachyte can be viewed along the gorge of the valley, and andesite at Blackford Quarry. In the Quaternary period, meltwater from glaciers and ice sheets weathered the bedrock of the valley, leading to the formation of the gorge, through which the Braid Burn runs.

Figure 4
Geological map of the Hermitage of Braid highlighting the andesite and trachyte lavas in the area
(Source: edinburghgeolsoc.org)

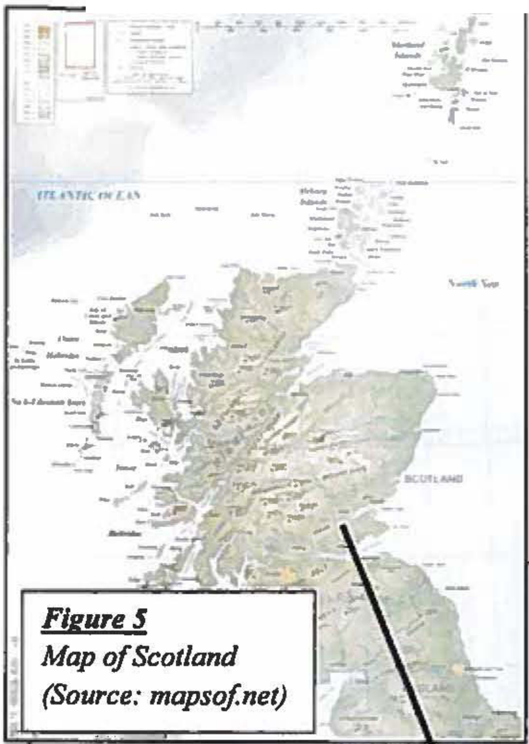


Figure 5
Map of Scotland
(Source: mapsof.net)

Figure 8
South facing sample slope in the woodlands of the Hermitage
(Samples taken 16/02/17)
(Source: Author's own photograph)

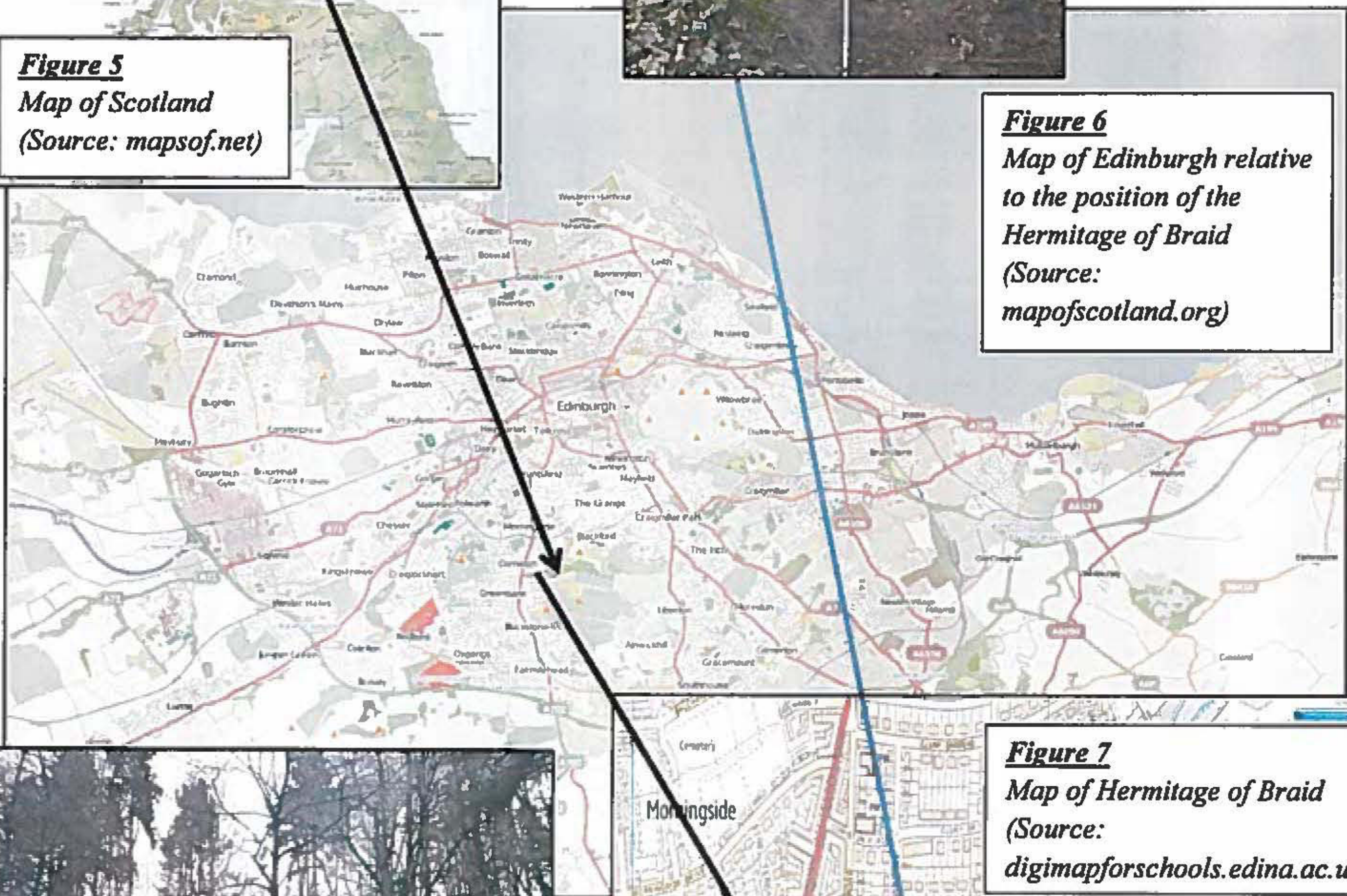


Figure 6
Map of Edinburgh relative to the position of the Hermitage of Braid
(Source: mapofscotland.org)

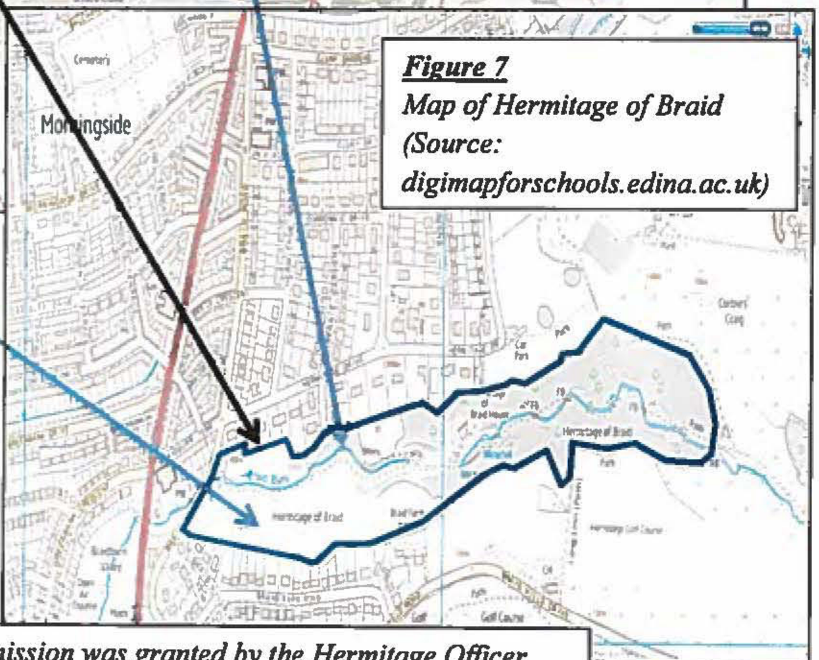


Figure 7
Map of Hermitage of Braid
(Source: digimapforschools.edina.ac.uk)

Figure 9
North facing sample slope in the woodlands of the Hermitage
(Samples taken 11/02/17)
(Source: Author's own photograph)

Permission was granted by the Hermitage Officer prior to conducting the study, as the area being sampled is protected land.

Aim

The aim of this study is to sample a North facing and a South facing slope , and to compare the soil characteristics of the two slopes.

Sampling

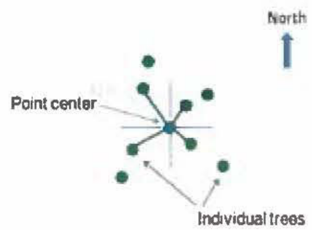
Soil samples and vegetation type and cover were sampled systematically at 5m intervals along a 20m transect. Ideally, the two slopes sampled were to be adjacent to each other; however, this was restricted due to inaccessiblity on the South facing slope . Systematic random sampling involves sampling from a random point in a regular interval. An advantage is that sampling points can be widely spaced when sampling in a large area. It is straightforward and time efficient, as opposed to other methods of sampling e.g. stratified sampling. However, sampling points do not have an equal chance of being selected, and may therefore highlight the *clustering effect*, which will show bias and over/under-representation of the underlying pattern.

Figure 10
Systematic sampling of vegetation on the South facing slope using a 5 x 5 square quadrat
(Source: Author's own photograph)

Research Question	Methodology	Limitations	Improvements
With distance up the slope, will soil moisture content (%) decrease?	A crucible was weighed on a three decimal place balance. Roughly 10g was placed in the crucible and exact mass recorded. This was repeated for the other 9 samples. The crucibles were placed in a pre-heated oven, and the oven thermostatically maintained at 90^{oC} for 48 hours. The crucibles were taken out of the oven using heat-proof gloves. The same three decimal place balance was tared, and the crucible re-weighed. The final mass was recorded. This was repeated for the other 9 crucibles. The % soil moisture content was calculated: $w = [W_2 - W_3] / [W_3 - W_1] \times 100\%$ • W_1 = weight of empty crucible • W_2 = weight of crucible and wet soil • W_3 = weight of crucible and dry soil	One value for % moisture content was obtained for each site. This may not have been representative of the population moisture content. The final mass of dry soil (no water content) was not known, as the samples were not reheated for a further 48 hours.  ***Figure 11*** *Soil sample weighed in a crucible using a 3 decimal place balance (Source: Author's own photograph)*	The procedure should have been carried out three or more times to ensure reproducible results and to minimise variability. Gravimetric analysis of soil moisture content could have been practiced. This relies on weighing the mass of soils in the crucible to constant mass.

Research Question	Methodology	Limitations	Improvements
How does soil texture change along a 20m transect?	The dry soil sample from the previous test was ground up with a mortar and pestle. The sample was transferred to a series of sieves, starting with the coarsest sieve (at the top). The lid was put on to prevent external influences. The sample was sieved for 5 minutes, and the individual sieves weighed using a balance. This was repeated for the other dry soil samples.	Soil could have still been present on the sieves after each analysis; therefore, an accurate mass of these particles could not be obtained. A whole number balance was used, which lacked precision and meant the weighed soil in the sieves were approximations. Organic matter may still be present in the sample. Fine soil particles are easily disseminated, and so the actual mass of soil in each sieve is less than the expected. Stones may have been present in the sample.	A very fine and sensitive balance could have been used to accurately weigh the dust particles. Hydrogen peroxide could have been added to the dried sample to destroy organic matter; this takes into account only the soil components sieved giving a more accurate percentage composition. High performance sieve shakers could have been used in place to disperse soil equally over the sieve, and to provide a more accurate result.

Research Question	Methodology	Limitations	Improvements
Will soil pH increase with distance up the slope?	Roughly 1cm^3 (≈1g) of soil was placed in the test tube. 1cm^3 of barium sulfate was transferred to the same test tube using a spatula. 7cm^3 of universal pH indicator was placed in the test tube using a dropper. The test tube was stoppered and inverted several times to ensure the contents were fully mixed. The solution was left to separate, leaving a distinct colour change.	The soil samples were collected after heavy rainfall, which will have affected the true pH of the samples. Indicators run on a logarithmic scale, thus an extra drop of indicator can completely change the colour of the end-point solution by a factor of 10. Universal indicators where the colour change spans the entire pH range allows for little precision in the colour change. The colour of the solution is subjective to the human eye. pH of soils can be altered by variables e.g. CO_2 partial pressure and solubility of soil particles, which were not tested for in this investigation.	An electronic pH meter could have been used in place to improve the accuracy of the pH value. *Palintest* soil kits could be used as means of field testing, which could produce results comparable to lab techniques.

Research Question	Methodology	Limitations	Improvements
How will vegetation type and cover change along a 20m transect?	A 5 x 5 square quadrat was placed randomly on the ground at 5m intervals. The abundance of each species of plants was counted and recorded. The % vegetation cover was calculated: (Abundance / 25) x 100%	Larger vegetation e.g. trees cannot be counted as being within a quadrat.	Sampling trees could be done so using the *point-quarter method* (a random sample point is sectioned into four 90° quadrants, and the tree closest to the sample point in each of the quadrants are identified).  ***Figure 12*** *Point-quarter method showing the closest tree to the point centre is chosen* *(Source: faculty.wwu.edu)*

Soil Acidity

Will soil acidity increase with distance down the slope?

Site Distance (m)	North facing slope	South facing slope
0	4.5	5.0
5	5.5	6.5
10	5.0	5.5
15	5.0	6.0
20	5.0	5.5

Table 1.1
Approximate pH of soil samples from 0 to 20m on North facing and South facing slopes

Figure 13
pH of North facing soil samples (Left: 20m Right: 0m) (Source: Author's own photograph)

Figure 14
pH of South facing soil samples (Left: 20m Right: 0m) (Source: Author's own photograph)

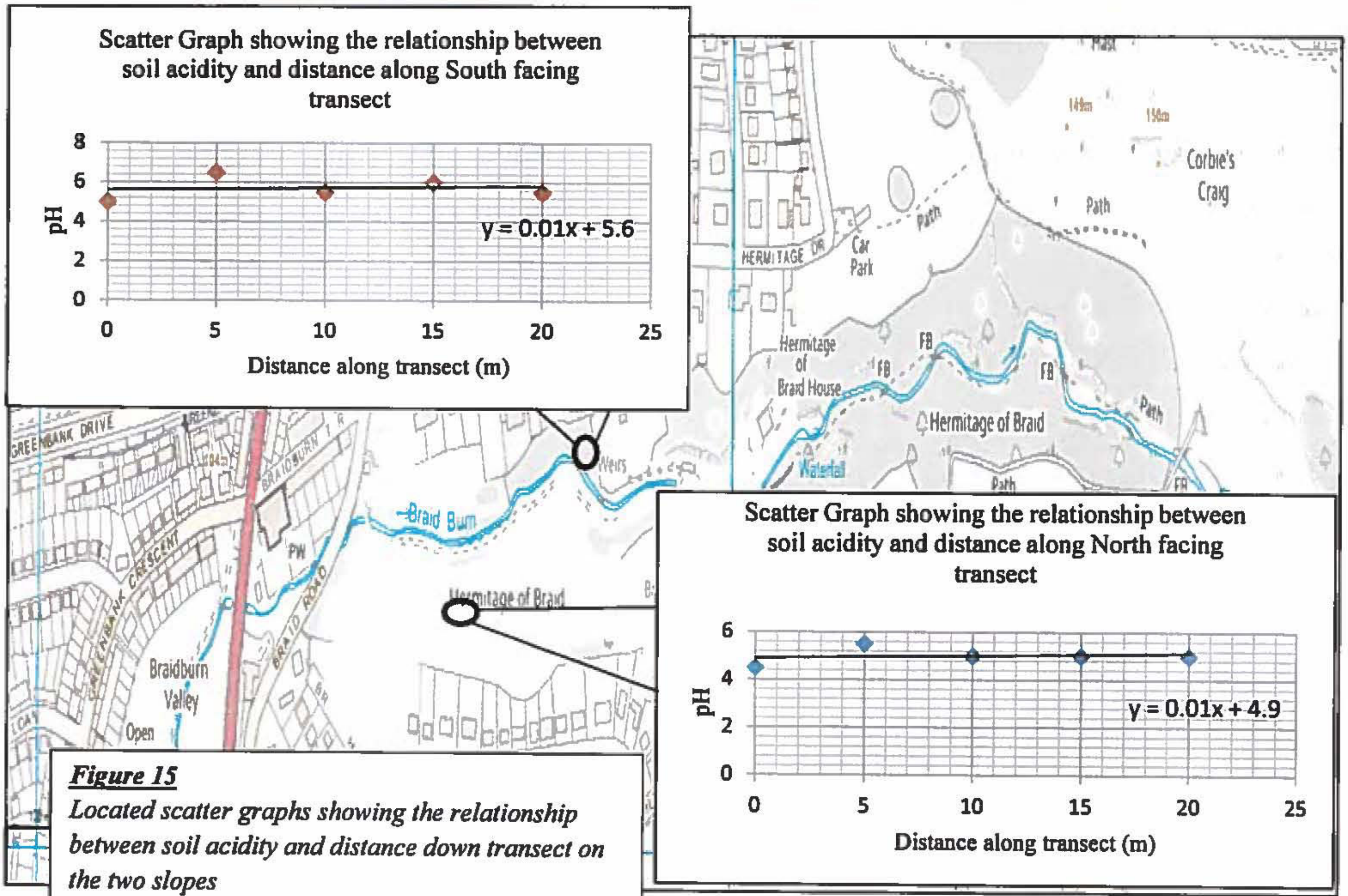


Figure 15
Located scatter graphs showing the relationship between soil acidity and distance down transect on the two slopes
(Source: Author's own diagram)

Results

Soils found on the South facing slope are less acidic than soil on the adjacent facing slope. Both soil pHs remain relatively constant and verge towards pH 7.

By observation, there is no linear relationship between a decrease in soil acidity (higher pH) with increased distance downslope.

Whilst soil samples were sampled along transects, neither show a gradual change in pH along the slope, so Pearson's Product was conducted to test whether there was a correlation between decrease in soil acidity and distance downslope.

North Facing Slope

H_0 : There is no correlation between an increase in soil acidity and distance down the North facing transect

H_1 : There is a correlation between an increase in soil acidity and distance down the North facing transect

Test at the 5% level (two-tailed test)

$S_{xx} = \Sigma x^2 - [(\Sigma x)^2/n] = 125.5 - [(25)^2/5] = 0.5$

$S_{yy} = \Sigma y^2 - [(\Sigma y)^2/n] = 750 - [(50)^2/5] = 250$

$S_{xy} = \Sigma xy - [(\Sigma x \Sigma y)/n] = 247.5 - [(50 \times 25)/5] = 2.5$

r (Pearson's Product moment correlation coefficient) = $S_{xy} / \surd(S_{xx} S_{yy}) = 2.5/\surd(250 \times 0.5) =$ 0.224 (3 sig. figs.)

$r_{3,0.95} =$ 0.878 * (where d.f.= (n-2))

As 0.224<0.878, accept H_0. There is evidence, at the 95% level, that there is no correlation between a decrease in soil acidity and distance down the North facing slope.

South Facing Slope

H_0 : There is no correlation between a decrease in soil acidity and distance down the South facing transect

H_1 : There is a correlation between a decrease in soil acidity and distance down the South facing transect

Test at the 5% level (two-tailed test)

$S_{xx} = \Sigma x^2 - [(\Sigma x)^2/n] = 163.75 - [(28.5)^2/5] = 1.3$

$S_{yy} = \Sigma y^2 - [(\Sigma y)^2/n] = 750 - [(50)^2/5] = 250$

$S_{xy} = \Sigma xy - [(\Sigma x \Sigma y)/n] = 282.5 - [(50 \times 28.5)/5] = 2.5$

r (Pearson's Product moment correlation coefficient) = $S_{xy} / \surd(S_{xx} S_{yy}) = -2.5/\surd(250 \times 1.3) =$ 0.139 (3 sig. figs.)

$r_{3,0.95} =$ 0.878 * (where d.f.= (n-2))

As 0.139<0.878, accept H_0. There is evidence that there is no correlation between a decrease in soil acidity and distance down the South facing slope.

*critical value taken from *Table of Critical Values: Pearson Correlation (Statistics Solutions)*[2]

Evaluation

Lack of differences in pH along both slopes is due to the uniform parent igneous rock which forms the Hermitage. Precipitation does not vary greatly between the Hermitage, so anomalies are likely due to other factors.

The Braid Road, a secondary road, which runs just outside the Hermitage, has influence on the overall stronger acidity (lower pH value) of soil samples on the North facing slope. Higher levels of NO and CO_2 contribute to the overall effect of soil acidification.

In Britain, soils tend to be more acidic: rainfall in high altitude 'leaches the basic cations (alkaline) out of the soil profile, and are replaced by acidic cations[3] *(eXtension, 2015)*. This is evident at the top of both slopes sampled. Also, roots of plants can generate CO_2 during photorespiration and release tiny amounts of organic acids into soil water.

Weaker acidities further downslope of the North slope could be due to the large amounts of dog use containing high levels of ammonia; the alkaline compound will have been readily converted to nitrate compounds and hydrogen ions naturally by bacteria in the soil in the Nitrogen Cycle.

The slightly weaker soil acidities at the upper slope (0m and 5m) of the South facing slope could be due to percolation of lime buffers practiced by some house residents behind the Hermitage. Flatter relief (slope angle of 11°) at 5m may provide evidence that water, at the 0m site, was stored in *depressions*, therefore the rate of outwash of water was slower, and the higher pH value was reflected in the reduced capacity of outwash of alkaline cations.

Soil Moisture Content

With distance down the slopes, will soil moisture content (%) increase?

Site Distance (m)	Moisture Content (%)	
	North facing	South facing
0	47.40	29.15
5	50.90	26.40
10	37.50	34.55
15	29.05	22.95
20	33.30	28.45

Table 1.2
Moisture Content (%) of the North and South Facing Slopes

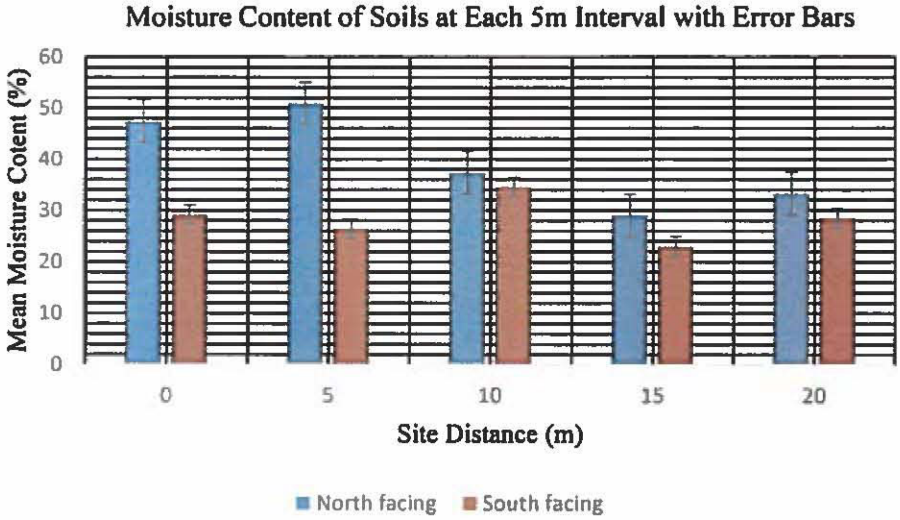


Figure 16
Bar graph with error bars showing moisture content of soils at each 5m interval (Source: Author's Own diagram)

Standard error of mean (S.E.) = s.d/√n

North Facing

S.E. = 9.282/√5 = 4.151 (3 sig. figs.)

South Facing

S.E. = 4.244/√5 = 1.898 (3 sig. figs.)

Results

Soils on the North facing slope had, on average, 11.3% more moisture content than soils on the South facing slope.

On the North facing slope, there appears to be a weak association between moisture content and distance down the slope. The standard error of mean suggests there is a 4.151 deviation from the population mean moisture content in North facing soil samples. Conversely, the South facing slope samples deviate from the population mean by 1.898. By taking the calculated standard error into account, the South facing sample means are more reflective of

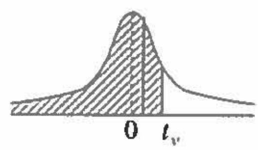
the population mean. Therefore, to lessen the extent of deviation from the population mean, more moisture content samples should have been taken.

It is difficult to ascertain, from the graph, the true relationship between slope aspect and soil moisture content. Therefore, a non-parametric Student's t-Test was conducted to establish whether the mean of the soil moisture contents on both slopes were different.

H_0 : There is no difference between mean moisture content on the North and South facing slopes

H_1 : There is a difference in mean moisture content on the North and South facing slopes

Test at 5% level (two-tailed test)



$S_{xx} = \Sigma x^2 - [(\Sigma x)^2/n] = 8185.385 - [(198)^2/5] = 344.585$

$S_{yy} = \Sigma y^2 - [(\Sigma y)^2/n] = 4076.49 - [(141.5)^2/5] = 72.040$

$S_{xy} = \Sigma xy - [(\Sigma x \Sigma y)/n] = 5629.995 - [(141.5 \times 198)/5] = 26.595$

n=5

r (Pearson's Product Moment Correlation Coefficient) = $S_{xy} / \sqrt{(S_{xx} S_{yy})} = 26.595/\sqrt{(72.04 \times 344.585)} = 0.169$ (3 sig. figs.)

$P\left(t_{n-2} \geq r\sqrt{(n-2)} / \sqrt{[1-(r)^2]}\right) = P\left(t_3 \geq 0.169 \times \sqrt{3} / \sqrt{[1-(0.169)^2]}\right) = P\left(t_3 \geq 0.297\right)$

As 0.297 is closer to zero than 3.182*, accept H_0. There is evidence that there is no major difference in mean soil moisture content between the two slopes as distance down the slope increased.

Although, statistically, there is no difference between moisture content between the two slopes, the (slight) changes in soil moisture can be observed as distance down the slopes increases.

*critical value taken from *Table 5: Student's t Distribution (Advanced Higher Statistics Statistical Formulae and Tables)* [4]

Analysis

Theoretically in the Northern Hemisphere, North facing slopes receive less sunlight, as the sun's output is indirect to the axis of the Earth's orientation, and therefore less water is evaporated into the atmosphere. The toe of convex-concave slopes is the area where moisture is greatest due to greatest kinetic energy of runoff and lack of free drainage.

The lower moisture content at the toe of the North slope, where ground vegetation was restricted meant the land was more exposed to physical weathering processes. The clay soils were therefore poorer in structure and lacked capability in containing rainwater. Evidence of poor soil structure include the ongoing growth of trees, which serve to enhance the root network system underground to improve drainage and aeration. The presence of stones also reduced the capacity of soil: less macropores means less rainwater can be held.

Low moisture content at the top of the South slope was perhaps due to greater ground vegetation cover (ivy and pine tree), which indicated that *capillary water* (water found on the micropores and absorbed by plant roots) was plentiful.

From 5m to 10m on the South slope, the steep slope along with rainwater from the previous two days (before samples were collected) led to overland flow, giving rise to the unexpectedly high value at 10m. Further evidence at the 10m site indicates that water was stored in *depressions*, which led to slow seeping of water downhill. This will have subsequently had an effect on the decreased moisture content at the 15m site.

Soil Texture

How does soil texture change along a 20m transect?

North Facing and South Facing Slopes Soil Texture

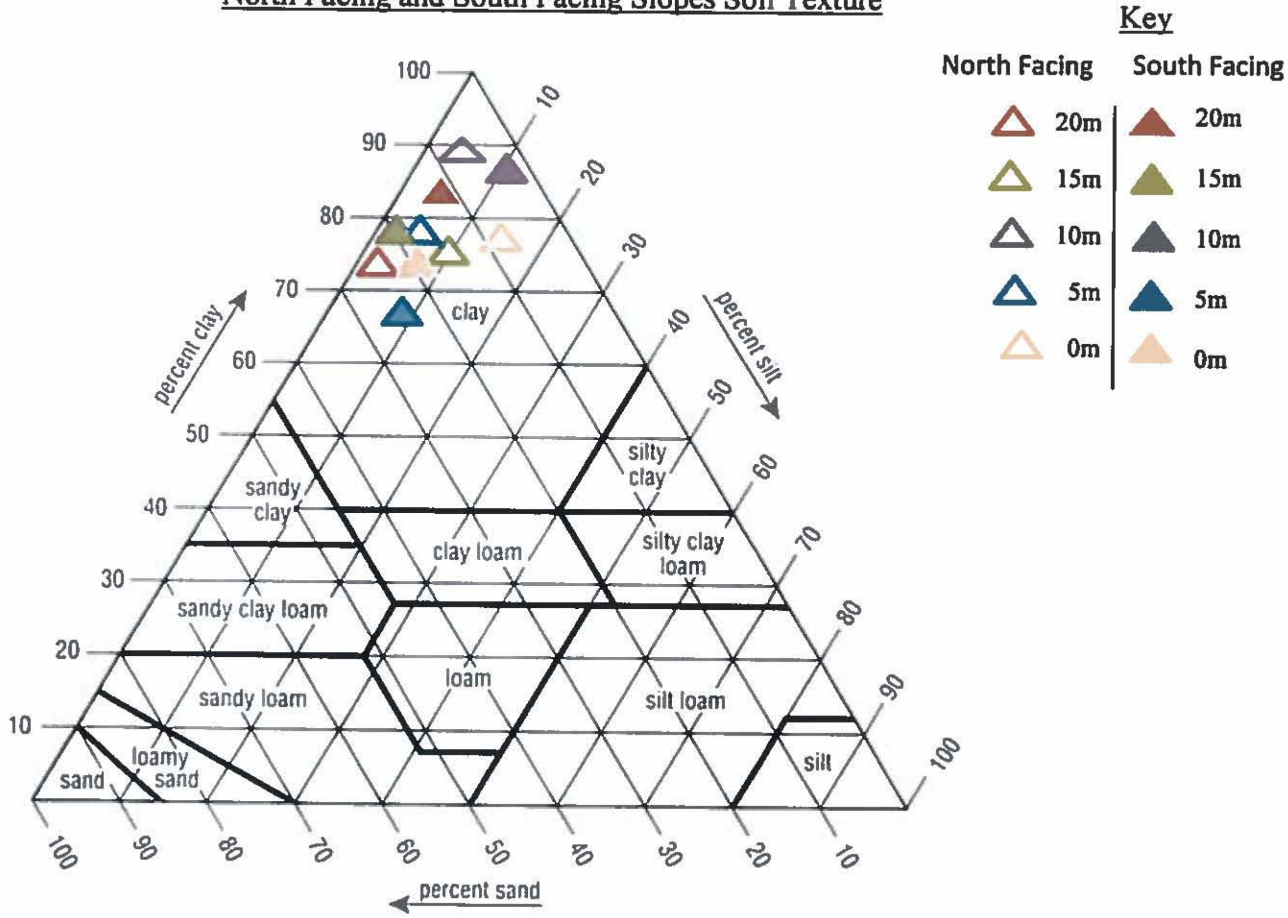


Figure 17
Triangular graph showing % clay at each site on the North facing and South facing slopes
(Source: had2know.com)
(Adapted by author)

Results

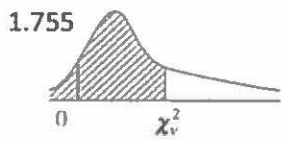
Both North and South facing soils were comprised of mainly clay (>50%), little sand (<30%) and very little silt (<20%), with no observable significant differences between soil textures on the two slopes.

From the triangular graph, there is a very weak association of percentage of clay found in soils in comparison to their relative sites/position. Therefore, a Chi Squared Test was conducted to determine whether there was an association between the two variables.

Site Distance (m)	0		5		10		15		20		Total
	O_i	E_i	O_i	E_i	O_i	E_i	O_i	E_i	O_i	E_i	
Clay (%) on North facing slope	74	73.1	76	70.6	89	87.7	73	75.6	72	77.1	384
Clay (%) on South facing slope	71	71.9	64	69.4	85	86.3	77	74.4	81	75.9	378
Total	145		140		174		150		153		**762**

H_0 : There is no association between % clay found in soils and distance of site down transect on both slopes

H_1 : There is an association between % clay found in soils and distance of site down transect on both slopes



Test at 10% level (one-tailed test)

$X^2 = \Sigma(O_i - E_i)^2 / E_i =$ 1.755 (4 sig. figs.)

$X^2_{4,0.90} = 7.779$

As 1.755 is closer to zero than 7.779, accept H_0. There is evidence to suggest, at the 90% level, that there is no association between % clay found in soils in the Hermitage of Braid and distance down transects on both slope aspects.

Analysis

The Hermitage is made up of clayey soils, and so the comprised clay texture in the soils from the two slopes in the area is not as a result of differences in aspect or gradient. The igneous rock found in the Hermitage remains uniform throughout. Since the climactic difference is not discernible either, it will not overly affect the weathering of the rock and the formation of mineral on both slopes. Therefore, over time, these will be difficult to find.

Clay is dominant in the Hermitage due to the geologic conditions in the past. Clay minerals can be classed as: kaolinite, illite and montmorillonite, and is formed by the chemical weathering of minerals which releases elements from pre-existing minerals into the soil - recrystallization then occurs which leaves the newly formed clay minerals. 'Minerals present in a soil have usually been through at least one cycle of weathering so that only the most resistant ones remain'[5] *(Bridges, 1970)*. Feldspars, micas and earth alkali metals present in the igneous rock are very susceptible to chemical weathering, and upon contact with solution, the ions are washed away into the soil solution forming nutrient enriched clay soils.

Soil Vegetation Type and Cover

How does vegetation type and cover change along a 20m transect?

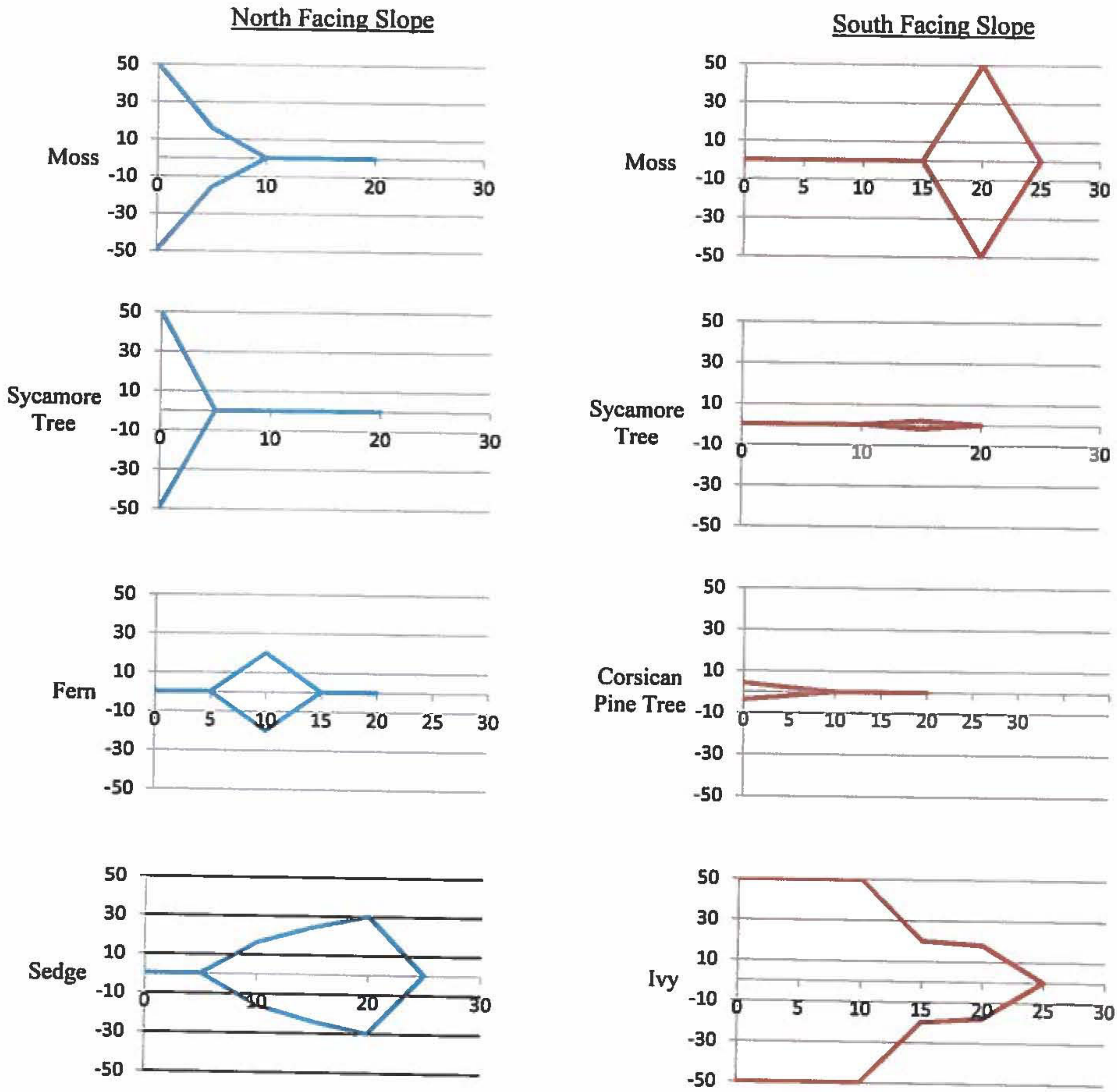


Figure 18
Kite diagrams showing distribution of vegetation cover (%) down the transect on the North facing and South facing slopes
(Source: Author's own diagram)

Results

Four plant species were found on the slopes, with sphagnum moss and sycamore trees common on both slopes. Abundance of moss on the North facing slope was found in higher altitude whilst the opposite was found on the South facing. More sycamore trees were found on the North facing slope at the 0m site, but on the adjacent slope, a lower abundance (-96%) of sycamore were found close to the toe of the slope. Ivy (a hydrophytic species) is common on the South facing slope.

The kite diagrams indicate difficulty in ascertaining the diversity of plant species along both slopes. Therefore, the Simpson's Index of Diversity test was conducted to establish both the *diversity* (similarity of the abundance of each species in making up the population) and *richness* (number of different species present).

North Facing Slope

Species	Number of plants in quadrat (N)	n(n-1)
Sphagnum Moss	33	1056
Sycamore Tree	3	6
Sedge	35	1190
Fern	10	90
Total	81	2342
	N = 81	**$\sum_{n(n-1)}$ = 2342**

South Facing Slope

Species	Number of plants in quadrat (N)	n(n-1)
Sphagnum Moss	4	12
Sycamore Tree	1	0
Corsican Pine Tree	3	6
Ivy	94	8742
Total	102	8760
	N = 102	**$\sum_{n(n-1)}$ = 8760**

North facing slope:

$D = 1 - \sum_{n(n-1)} / N(N-1)$

$= 1 - 0.3614$

$= 0.639$ (3 sig. figs.)

South facing slope:

$D = 1 - \sum_{n(n-1)} / N(N-1)$

$= 1 - 0.8503$

$= 0.150$ (3 sig. figs.)

As 0.639 is closer to 1 (infinite diversity) than 0.150, the North facing slope had a greater diversity of plant species. In practice, although both slopes had the same richness of plant species, plants on the North facing slope were more evenly distributed. Ivy on the South facing slope was the dominant species, and thus led to less diversity.

Evaluation

Soil-plant relationship is considered to be a *two-way* process: soils affect the presence of various plant species, but in turn, plants can modify the soil by removing nutrients, and increasing aeration via rooting.

Sphagnum moss was common on both slopes because of the relatively high level of rainfall intake on the sites where moss was present. 'Plants adapted to waterlogged conditions have increased availability of soluble sugars and greater activity of glycolytic pathway'[6] *(Sairam,* *Kumutha, Ezhilmathi and Deshmukh, n.d.)*, therefore producing more sugar for plant growth, as chemical compounds are most soluble in slightly acidic soil solutions. The different distributions of moss on the two slopes are thought to have been due to varying drainage patterns.

Moss can 'break down rock and soil, making a more hospitable environment for vascular plants'[7] *(Wonderopolis, n.d.)*, and the small concentration of fern on the North side may suggest the plant had recently moved into the area.

The colonisation of Ivy down the South facing slope is due to interspecific competition (individuals of different plant species compete for the same resources). The plant survives in soils of weak acidity and moisture ranging from slight moisture to drought. Since the South facing slope receives more sunlight, moisture is likely to evaporate, and can therefore present conditions for optimum ivy growth.

South facing slope environments are more xeric, which means tree growth is less conducive. Sycamore found on the South side could have been due to the displacement of seeds by soil biota and wind patterns. On the North slope, the high concentration of trees at higher altitudes presented shelter which reduced the effect of the wind, thus the seeds were less likely to have been blown downhill.

Sedge found at the shoulder to the toe of the North facing slope are hydric and require constant moisture. At higher altitudes, the absence of sedge is due to the greater soil moisture content which completely depletes the transfer of oxygen and other gases between the clay soil pores and atmosphere.

Conclusion

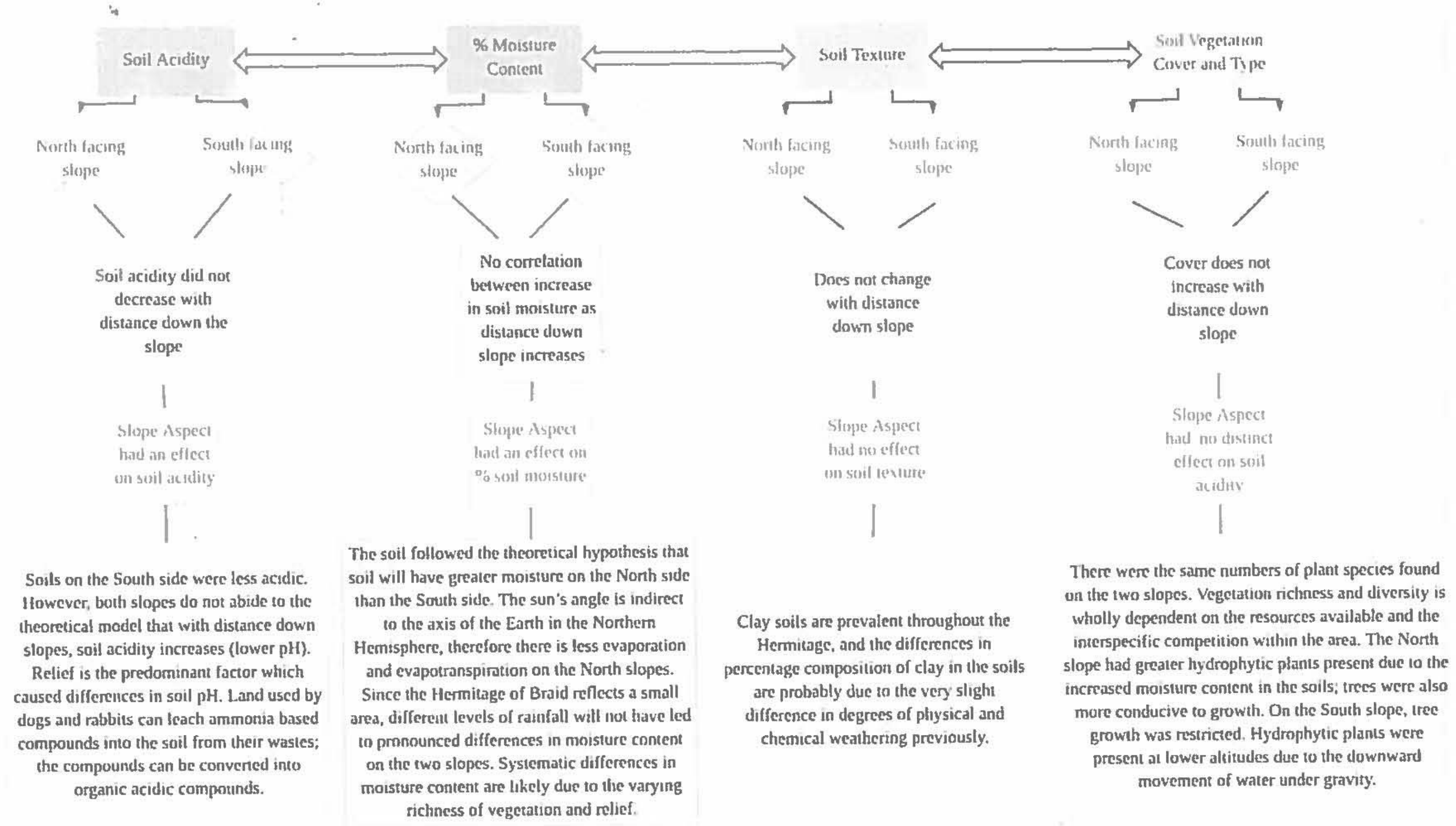


Figure 19

Summary of the soil characteristics on both slopes and the comparison between the North and the South facing slopes (Source: Author's own diagram)

Appendix

Site Distance (m)	Slope Angle (°)	
	North facing	South facing
0	16	14
5	14	11
10	22	19
15	31	25
20	0	0

APPENDIX A
Slope angles of the North and South facing slopes at 5m intervals

References

Book Sources

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Diagrams

Otherwise stated below, all other diagrams are taken and adapted by the author of this study.

Figure 2: URL:
https://soils.ifas.ufl.edu/faculty/grunwald/teaching/eSoilScience/formation.shtml

Figure 4: URL: http://www.edinburghgeolsoc.org/downloads/rigsleaflet_blackforda4.pdf

Figure 5: URL: http://mapsof.net/united-kingdom/scotland-topographic-map

Figure 6: URL: http://www.mapofscotland.org/map/edinburgh/mapofedinburgh.html

Figure 7: DigiMaps for Schools
URL: http://digimapforschools.edina.ac.uk/

Figure 12: URL: http://faculty.wwu.edu/wallin/envr407/407_PCQ_data_and_lidar_lab.html

Figure 17: URL: http://www.had2know.com/garden/classify-soil-texture-triangle-chart.html
(Adapted by author)